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The Scientist's Concept of the Physical World

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THE SCIENTIST'S CONCEPT OF THE PHYSICAL WORLD

BY WILLARD GARDNER

FIRST ANNUAL FACULTY RESEARCH LECTURE

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INTRODUCTORY NOTE

The following lecture by Professor Willard Gardner is the first in a series to be presented annually by a scholar chosen from the resident faculty at Utah State Agricultural College. The occasion expresses one of the broad purposes of the college Faculty Association which is a voluntary association of members of the faculty. The 1942 lecture appears under the Association's auspices as defined in Article II of its Constitution, amended in May 1941:

"The purpose of the Organization shall be . . . to encourage intellectual growth and development of its members . . . by sponsoring an Annual Faculty Research Lecture . . . The lecturer shall be a resident member of the faculty selected by a special committee which is appointed each year for this purpose."

On November 27, 1941, after organization and preliminary meetings, the committee met and elected Professor Gardner to the first lectureship thus established and sponsored. On behalf of the men and women of the Association, a company devoted to the scholarly quest and to the teaching of truth, we are happy to present Dr. Gardner's paper: "The Scientist's Concept of the Physical World."

COMMITTEE ON FACULTY RESEARCH

FOREWORD

To those who are aesthetic, there is perhaps nothing more inspiring than a beautiful sunset, with brilliant colors above the horizon and with banks of dark clouds above, set in the deep blue of the heavens, or the brilliant hues of the rainbow forming a halo about the majestic mountain with its coat of green, purple, brown, or gray. By these things are the emotions stirred.

The physicist too is emotional but he is also at times realistic. He becomes sentimental but he also seeks to explain the behavior of nature. By means of devices and instruments his perceptual world is expanded. He tries to translate it all into numbers and equations. He seeks for invariance in a world that constantly changes. By the power of his intellect he achieves a measure of success; he discovers harmony in chaos, and he lays a foundation upon which the engineer and the artisan may build.

Of the things that are perceived and imagined he constructs his own world and modifies this conceptual universe from day to day to conform with the facts of observation and of experimentation. One generation builds upon the achievements of those preceding and hands them down, appropriately modified, to generations that follow. The facts and the realities persist but the interpretations change.

The developments of the twentieth century in particular impress upon us the necessity of including with our concepts of nature the concept of endless change in the subjective world.

This article has been influenced greatly by the somewhat unique presentation of Richtmyer and Kennard in their new book, and by Cajorie in his most interesting history of physics. Quotation marks have been used in some cases and omitted in others and it is hoped that this will prove to be an acceptable procedure.

WILLARD GARDNER

Logan, Utah
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INTRODUCTION

THE puzzling problems of modern physics are best understood if we try to anticipate some of the defects inherent in the methods of experimental science. Knowledge concerning any physical object or any physical phenomenon that comes to us through the sense organs is always incomplete, but our thinking is determined primarily by these impressions.

Let us consider for a moment a simple illustration. A hot clinker is physically different from a cold one and every normal human being would at some time or other in his life become inquisitive as to just what makes the difference. To the organs of sense, substances of this kind are rigid and inert but to the physicists of the twentieth century they are thought to be composed of vast numbers of small particles, each one moving about violently in a limited space and coming into contact frequently with neighboring particles. This motion constitutes our present-day concept of heat, but until about the middle of the nineteenth century heat was thought to be a fluid, to which was given the name *Caloric*.

In the natural sciences inductive reasoning is utilized in developing fundamental principles and it becomes necessary to recognize, therefore, an element of serious weakness in their logical structure. To illustrate this point let us consider the law of gravitation. We might provide a large bell jar from which all air had been removed and drop various bodies to find out about their behaviour. The inductive logic that forms the basis of this law leads us to believe that all these bodies, regardless of their size or their physical nature, would gain speed at a rate approximately thirty-two feet per second *per second*.

Everyone believes that there is abundant intuitive justification for developing unbounded confidence in generalizations of this kind. As a matter of logic, however, the conclusion is not justified. The fact that an event happens once, twice, or many times, does not constitute a priori evidence that it must continue to happen. In the nineteenth century the physicists had unbounded confidence also in the law of conservation of mass, but the experimental results of the present century lead us to believe that it is very far from the truth for bodies that move with violent speed.

In this discussion the word *law* will be used repeatedly. It is not intended to imply, however, that the physical laws have anything whatever to do with edicts or decrees. They are inductive generalizations that seem to us to be true. They are founded ultimately on experiment and not necessarily on logic. Deductive reasoning and mathematics are used extensively, but all these generalizations that form the bases of deductive inferences obtained in this rigorous manner must be construed as hypothetical foundations that may be subject to revision from time to time.

It should be emphasized also that many of the concepts that have lived and died have been invented. These inventions have been actuated perhaps by impressions of things that have been perceived, but the imagination is influential in shaping our concepts. This, we believe, was particularly but not uniquely true of the ancient scholars. They were given to speculation but the scientific men of the experimental era too have indulged in speculation.

Much stress has been placed by the physicists and the historians upon the revolutionary character of the experimental era, but it should not be overlooked that the science of physics would scarcely deserve the name were it all experimental. It would be cumbersome, monotonous, and without very much significance or utility. On the other hand, owing to the fact that some of the best intellects have been enticed into this fascinating and fruitful field of human endeavor, it embraces a comprehensive and concise body of knowledge that is surpassed in no other field. It is practical knowledge that deals with mechanical inventions, with machinery, with communication, with transportation, with navigation, and indirectly with all the practical affairs of human beings. It has been made comprehensive and concise because its problems have been uniquely suited to the application of mathematics. One of the outstanding and important contributions made by Sir Isaac Newton was his discovery of the fluxions, or what came later to be known as the calculus. It has been uniquely effective in aiding the physicist to conserve his mental processes and to strengthen his power of deductive inference. Many of the concepts of the physics of 1942 originated in mathematics. Such quantities, for example, as field intensity, potential, entropy, angular momentum, stress dyadic, curvature tensor, wave packet, would never have been conceived had physics developed without the aid of advanced mathematics.

One of the major purposes of this introductory statement is to emphasize the fact that the physicists must be prepared to revise their thinking from time to time as new information comes to light. We have no means of knowing in advance how violent may be these revisions. It is the essential purpose of this article to present in perspective some of the important developments in physics, to point out some of the most important laws and concepts, and to indicate some ot the difficulties that have presented themselves, particularly in the twentieth century.

PHYSICS IN ANCIENT TIMES

Until the beginning of the sixteenth century, so far as we know, there had been no programs of planned experimental study and research. It would not be just, however, to imply that careful consideration had not been given to many natural phenomena in ancient times. In mathematics, metaphysics, literature, and art the Greeks displayed wonderful creative genius, even though in natural science they achieved comparatively little. They lacked the incentive to conduct experimental tests, although some of their ideas seem to us to have been near the truth. They delighted in speculative philosophy.

Anaxagoras in the fifth century B. C. held the view that the sun places the brightness in the moon. He taught that changes in matter are due to combinations or separations of small, invisible particles. Empedocles, a contemporary, believed that light is due to the emission by the luminous or visible body of small particles that enter the eye and are then returned from the eye to the body, the two "streams" giving rise to the sense of form and color. Democritus who lived in the fourth century B.C. postulated that the universe consists of empty space and an (almost) infinite number of indivisible and invisible particles which differ from each other in form, position, and arrangement. Archimedes as early as the third century B.C. discovered the famous principle that bears his name. These ancient people were familiar with electric and magnetic phenomena and they had learned many things about reflection and refraction of light.

The following quotation from Aristotle, which illustrates the character of some of their speculative reasoning, constitutes his proof that the world is perfect:

"The bodies of which the world is composed are solids, and therefore have three dimensions. Now, three is the most perfect number,—it is the first of known numbers, for of *one* we do not speak as a number, of *two* we say both, but *three* is the first number of which we say all. Moreover, it has a beginning, a middle, and an end."

He redeemed himself in the following pronouncement that is worthy of the sixteenth century:

"Lack of experience diminishes our power of taking a comprehensive view of the admitted facts. Hence, those who dwell in intimate association with nature and its phenomena grow more and more able to formulate, as the foundation of their theories, principles such as to admit of a wide and coherent development; while those whom devotion to abstract discussions has rendered unobservant of the facts are too ready to dogmatize on the basis of a few observations."

THE EXPERIMENTAL ERA

It was left for Copernicus, Tycho, Kepler, Galileo, Newton and their contemporaries to usher in an era that led to a greatly expanded conceptual universe and to a deeper insight into the phenomena of nature. Newton contributed greatly to the physics that survives in our day. The law of gravitation, no doubt, constitutes his outstanding and most far-reaching achievement. Not only does it form the basis for an impressive science of celestial mechanics but it serves to introduce the concept of invariance. Our concept of the gravitational field vector originated in this law and in the mathematics required to give it quantitative expression. The electrostatic field intensity had its origin in Coulomb's law of electrostatics, a law that has the same mathematical form. These fields seem to us to be real though not immediately perceived.

Regarding the concept, potential: We can imagine a mass of unit quantity being lifted a definite height against the field of gravity, or an electric charge of unit quantity being lifted against the electrostatic field, requiring an amount of work in each case that depends in two ways on the distance lifted: (1) the weight decreases in accordance with the inverse square law of gravitation as the distance increases: (2) the work is measured as the product of the force and the distance. For each point in space we thus come to associate a number purporting to measure the work characterizing the point and to the quantities thus conceived to be measured we assign the name potential. The potential is thus a quantity that seems to have physical reality but it does not react with the organs of sense. It is intimately associated with things that are physical but it has a mathematical connotation. With our eyes we have seen objects that are composed of matter, some of them being charged with electricity. These things seem, therefore, to be perceived, although the electric charge reacts somewhat more indirectly with the organs of sense. These objects are localized; they are to be found at a particular place. The potential and the field intensities, on the other hand, are distributed throughout space. They cannot be seen or felt. They seem, however, to be real; they are at least conceptual realities.

The caloric, or what was thought to be the heat fluid, was an invention but it was endowed with some of the properties of water and air, substances that are perceived. It was thought to be a substance though perhaps without weight or inertia.

At the time of the Greeks and at the time of Newton moving corpuscles seemed to explain the transmission of light, but Huygens, a contemporary of Newton looked for the explanation in a wave motion in some kind of all-pervading fluid medium. This helped to explain the phenomenon of interference and of polarization, neither of which found ready explanation on the corpuscular theory. The electrostatic and electromagnetic fields that became so important to Michael Faraday in his extensive and epoch-making experimental researches in electricity and magnetism were likewise better understood on the hypothesis of the existence of a lumeniferous ether.

In Benjamin Franklin's time there was much discussion as to whether or not electricity could be explained as fluid motion. There were two kinds of electricity and this suggested a two-fluid theory. To the mind of Michael Faraday the magnetic and electric fields could be visualized in terms of lines of force. Cables, ropes, cords, and rubber bands could transmit forces. These substances were readily perceived and the magnetic line of force as a concept presented itself through analogy.

In ancient times the Greeks had conceived the idea that magnetism could be explained as the action of a weightless fluid that could penetrate magnetic substances and pass from one such substance to another.

It was in 1798 that Count Rumford conducted experiments that led to the kinetic theory that replaced the caloric heat fluid. He was engaged in boring out cannon for the Bavarian government and was impressed by the large quantity of heat produced. If the caloric theory were correct, then this great evolution of heat ought to result in a loss of "something." He set out to discover by experiment the answer to the question. By a mechanism worked by two horses he caused a blunt steel boring tool to rotate, under great pressure, on a piece of brass, the brass and tool being immersed in water. In two hours the water actually boiled. He reasoned thus:
" . . . anything which any isolated body, or system of bodies, can continue to furnish without limitation cannot possibly be a material substance; and it appears to me to be extremely difficult, if not quite impossible, to form any distinct idea of anything capable of being excited and communicated in the manner heat was excited and communicated in these experiments, except it be motion."

The physicists of 1942 accept this conclusion without hesitation and the logic sounds better than does that of Aristotle in his proof that the world is perfect. It would be a profitable exercise, nevertheless, for the physicist to contrast this inductive logic with the logic of mathematics.

At the close of the nineteenth century gravitational fields, electrostatic fields, magnetic fields, light waves, sound waves, molecules, atoms, the kinetic theory, the lumeniferous ether, the law of conservation of mass, the law of conservation of energy, Newton's laws of motion, his law of gravitation, Coulomb's law of electrostatics and a corresponding law for magnetic poles, Faraday's laws of electrolysis, Maxwell's theory of the electromagnetic field, the second law of thermodynamics, Fermat's principle, Hamilton's principle, the principle of least action, and the theory of probability were among the concepts and universal laws that had survived. Detailed studies had been made of the properties of solids, liquids, vapors, and gases; Hooke's law of elasticity, the laws of dynamics of fluids, the gas laws, and the laws of chemical equilibrium had been established, and these laws and principles had been applied to the solution of numerous practical problems of applied physics, chemistry, and engineering.

THE FOUR PERIODS

In their book, *Modern Physics*, Third Edition, 1942, Richtmyer and Kennard point to four periods in the development of the science of physics. The first included all time to about 1550 A. D., this date marking the approximate beginning of the experimental period. The second period extends from 1550 to 1800, and includes the contributions of Galileo, Newton, Huygens, Boyle, and others. The third period extends from 1800 to 1890 and includes the epoch-making work of Count Rumford and Joule that paved the way for our present kinetic theory of heat; the work of Thomas Young and his proposal of the principle of interference of two beams of light which resulted ultimately in the triumph of Huygen's wave theory of light; the epoch-making experimental work of Faraday supplemented by the mathematical theory of the electromagnetic field by the great mathematical genius Maxwell.

Concerning the fourth period these authors state:

"The fourth period may be said to begin with the discovery of the photoelectric effect (1887). In the first decade of this period there were discovered, in rapid succession: X-rays in 1895; radioactivity in 1896; the electron in 1897. The beginnings of the quantum theory date from 1900. From 1900 to 1925 the older form of the quantum theory grew to occupy a commanding position in almost every field of physics; the nuclear type of atom and its relation to the emission and absorption of radiation were developed to a high degree; research in physics, stimulated in part by these outstanding discoveries and in part by the extensive industrial applications, increased to almost a new order of magnitude. Then, when physicists were just beginning to grow accustomed to the use of either the classical theory or the quantum theory, according to the problem in hand, the theoretical papers of de Broglie, Heisenberg, and Schrödinger, and the experimental work of Davisson and Germer and G. P. Thompson, beginning about 1925, initiated the new form of quantum theory known as wave mechanics. This new theory has effected, in a radical and remarkable way, a synthesis of classical and quantum physics and has already exerted almost as profound an influence on physics as did the discoveries of Newton over two and a half centuries ago. Perhaps the historian of a few decades hence may designate 1925 as marking the beginning of a fifth period in the history of physics."

THE TWENTIETH CENTURY

It is to this period that we now turn. We recall that the impressions that come to us directly through our organs of sense, supplemented by the refined instruments of modern science, can at best be no more than an incomplete counterpart of the physical world. We recall that the logic of physics is fundamentally inductive. We recall, however, that mathematics has profoundly influenced the nature of our concepts. Let us make a serious effort to appreciate deeply the significant fact that the real world is not what it seems to us. Let us remind ourselves that our thinking is influenced by our experiences and that had we been endowed with organs of sense that could observe ultra-microscopic detail our primitive impressions would have been vastly different. In this connection, a remarkably significant phenomenon known as the Brownian movement is revealed to us by a high-power microscope. Small colloidal particles suspended in a fluid medium are observed to move about erratically, to and fro, in a limited region. This motion is thought to be due to the repeated bombardment by the molecules of the liquid although they are far too small to be observed directly.

The physics of the twentieth century embodies in substance most of the laws and concepts enumerated but it does a great deal more than that. It pictures a world that is composed of electrons, positrons, neutrons, and photons. But what are these fundamental entities? Are they fundamental and final? Inductive reasoning might lead us to believe that they in turn are composed of sub-electrons, sub-positrons, sub-neutrons, and sub-photons, but the experimental information obtained since 1887 seems to nullify the inference.

We have with our hands obtained direct impressions concerning matter in bulk. We lift a stone against the field of gravity, we throw it, and we become perceptually aware of its mass, its rigidity, its color, its roughness. We can with the aid of a hammer reduce it to powder and we conceive the particles being divided and subdivided down to the atom. We observe that the roughness of the stone's surface is due to the fact that small granules are cemented together, and that these in turn are composed of smaller granules, but we seem to interrupt this inductive process. We shift to the intuitive impressions that guided Aristotle in his proof that the world is perfect and conceive the atom as being a small inert rigid sphere. This inductive logic fails to reveal the violent motion of the molecules. This was conceived in much the same way that the caloric had been conceived previously but it proved to be more successful.

This inductive logic did not reveal any information regarding the structure of the molecule nor of the atom. The chemists had developed a picture of the molecule that was compatible with the experimental knowledge they possessed regarding chemical reactions. To do this required a careful consideration of numerous experimental facts. Faraday's laws of electrolysis, considered in connection with the electron theory, provided an excellent background upon which was built a successful theory of valence, but inductive inference alone was not adequate to this task. Hypotheses were set up and checked to see if they fulfilled all the many conditions required by the experimental facts. Similar hypotheses were introduced to explain the manner in which the atom was built up of the fundamental entities mentioned, and an extremely successful theory of the structure and of the dynamics of the atom was developed. The difference between the various atoms was resolved into architecture. X-rays, radioactivity, cathode rays, and the qualitative aspects of the photoelectric effect were accounted for.

By some means or other the light waves were able to bombard the electrons in a metal and send them out into space at high speed. The swiftly moving cathode rays were able to excite X-rays by bombardment of a target, and the heavy uranium molecules were conceived to be unstable, thereby losing electrons, alpha particles, and gamma rays. There was no hidden mystery in the X-rays and the gamma rays. They could be interpreted as light waves of extremely short wave length and of corresponding high frequency. The alpha rays turned out to be ionized helium atoms.

LIGHT QUANTA

However, among these tremendously important discoveries of the late nineteenth century was included a quantitative result that gave rise to serious difficulty. On the basis of all the theory and experiment that had formed the physics of this period it was to be expected that the kinetic energy with which the electrons would be ejected from the metal by the light waves shining on it would be determined by the intensity of the light beam. On the contrary, however, this energy of motion of the ejected electron, when properly corrected to take account of the energy required to bring it to the surface before ejecting it, proved to be directly proportional to the frequency and not to the intensity of the light wave.

On the new theory of the structure of the atom, hydrogen was presumed to consist of a proton as a massive positive nucleus with an electron traveling about it in an orbit similar to that of the earth about the sun. Gaining kinetic energy from an outside source such as a beam of light meant, on the classical theory, that its orbit could be enlarged by any desired amount depending upon the intensity of the light beam. However, this new quantitative experimental result seemed to indicate that the energy quantity obtainable by the electron from the light must be equal to the product of an integer, another definite number known as Planck's constant, and the frequency of the light. In effect then the orbit would have to be increased a finite amount or not at all if its energy increment were to come from a monochromatic ray of light.

This is of course a technical problem and a difficult one but a careful consideration of this photoelectric law seems to demand a major revision of the concepts that had become rather firmly fixed in the minds of the physicists at the beginning of our present century pertaining to the fundamental nature of matter and energy. Throughout the entire experimental era, however, experimental facts have constituted the final court of appeal for the physicists, and their only recourse seemed to be to set about to make violent modifications in their thinking, and, as a result, they obtained a new mechanics for small particles wholly different from the mechanics of matter in bulk and a mechanics that required an ultimate particle with extraordinary properties.

The violent agitation of the individual molecules in a static rigid clinker seems to have been an acceptable explanation of the phenomena of heat, and there seems to remain a proper niche for secondary erratic motion of the electrons, the positrons and the other "composite" entities of which the atom is built. At the present stage of thought, however, something very much different seems to be required.

It would seem a bit fantastic were Baron Munchausen to tell us that he had discovered a strange land inhabited by strange people who were eternally dancing about, vanishing out of sight and returning suddenly at a distant place, rushing away in elongated and extended fuzzy indistinct ripples. It would indeed be something quite out of the ordinary but we discover when we stop to think of it that the profound and overwhelming doubt we entertain is born of our own experiences. It is absurd because we have never before nor since heard of such a thing. Neither has anyone ever seen an electron or a positron or a photon. They are conceptual entities that have been localized in space in our thinking because all the macroscopic substances with which we are familiar are localized in space.

We shall return to this theme briefly again, but in the meantime let us stop to consider another experimental result that also came in the year 1887, a result that was perhaps even more revolutionary in character than the Einstein photoelectric law.

RELATIVITY

It will be recalled that the work of Huygens, Maxwell, and others had led to the discarding of the corpuscular theory of light in favor of wave motion in the ether. A beam of red light, on this theory, consists of a series of waves uniformly spaced and separated in time by equal time intervals; whereas, a beam of violet light consists of a series of similar waves spaced more closely and separated by shorter time intervals, both rays traveling through the ether at the constant speed of light. A vital feature of this wave theory was that, aside from the local wave motion, the ether fluid in bulk was at rest.

Let us imagine a physicist moving at a high speed toward another physicist a great distance away. He sends out a light signal making use of red light of long wave length and long period of vibration. On the basis of the wave theory we conclude that the wave spacing would actually be shortened because of the motion of the light source. Its motion would effectively telescope the waves. The wave fronts would reach the second physicist at more frequent intervals than those with which they left the source because of the telescoping effect, and the light would appear to the receiver to be violet. A little careful consideration will convince us that this is thoroughly compatible with the wave theory. Let us note also — and this is of vital importance — that the wave lengths in the ether could be matched in one-to-one correspondence with small intervals of *absolute* time. The ether would thus be a great master-clock.

But let us digress for a moment. In 1887, Michelson and Morley at the University of Chicago carried out a carefully planned experiment for the purpose of measuring the speed of the earth through the ether. It was known to make a journey of about a half billion miles in a year and on the basis of the wave theory its speed through the ether could be measured by means of an interferometer, an instrument that was designed for this specific purpose. The result of this experiment seemed to indicate that the earth was not moving at all. The test was repeated and other tests were made with the same result in every case. The leading physicists in all countries seemed to be compelled to concede the validity of the result. It was quite out of the question to return to the old geocentric theory that made the earth unique among the heavenly bodies. Neither could the experimental facts be disregarded. The only alternative remaining seemed to be to abandon the ether as a concept, but this too led to another serious difficulty, as will be seen if we return to our problem.

Without regard to the question as to how light is transmitted the relative motion of the two physicists would give rise to the change in color of the light. This is in harmony with a well established experimental result known as the Doppler principle. The time intervals separating the signals sent out as recorded by the sender would be different from those observed by the receiver. We recall that one of the physicists was moving and the other was at rest, the implication being that the ether was to represent the fixed reference frame. Abandoning the ether concept, however, leaves an obvious uncertainty as to which of the time intervals, if either, is correct. This dilemma will be much magnified if we include several physicists each one moving relatively to each of the others. In a word, the inferences from this experiment seem to throw great confusion into the concept of *absolute* time. This much seems unquestionably to be true; the time that we use, however carefully it may be corrected and adjusted for longitude, obviously is not *absolute* time. Each individual physicist has been observed to have an individual time scale.

WAVE MECHANICS

At the close of the third period the physicists had come to the conclusion that the science of physics had been completely organized, aside from the routine task of making refined measurements of the numerous physical constants that were involved in the theories. As a result of the powerful influence of mathematics it had become a dignified body of knowledge that seemed to be final. The application of its principles to industry had succeeded wonderfully. Steam engines, electric motors, electric lights, the telegraph, the telephone, and numerous other inventions, had come into general use. Great advances had been made in the application of thermodynamics to the development of the internal combustion engine. Furthermore, by introducing the ether, the gravitational field, the electromagnetic fields, and other conceptual realities as companions to the entities that had appealed directly to our senses, the physical domain had seemed to be pretty well described. The success of the ether as a useful medium had served to ease the pain incident to conceiving the existence of such an extraordinary substance.

But the Einstein photoelectric law and the Michelson-Morley experiment served to introduce great confusion into the peaceful state of mind of this period. The attraction of the moon on the water of the ocean gives rise to tidal motion, and this in turn to the dissipation of extremely large quantities of potential energy, and as a result the orbit of the moon is gradually decreasing in size. Prior to this time it would have been thought ridiculous to believe that it would lose energy in finite steps, but the Bohr theory of the hydrogen atom that was based on this photoelectric effect required losses or gains in the energy of the revolving electron in just this extraordinary manner.

It would prolong this discussion far beyond the limitations that must be imposed to undertake to present the details of the marvelously successful efforts that have been made by the physicists of the twentieth century in devising a new wave mechanics that takes proper account of these new and revolutionary discoveries. Suffice it to say that the ingenious—if not miraculous—efforts made by such outstanding physicists as de Broglie, Heisenberg, Schrödinger, Dirac, and Jordan have largely resolved the analytical difficulties. A second order partial differential equation that involves very strangely a dependent variable, the exact meaning of which no one knows, together with the old-fashioned variables including three space coordinates and physical time, seems to summarize the essential features of this new wave mechanics in an extremely comprehensive manner. This is known as the Schrödinger partial differential equation and was modified by Dirac and Jordan to take proper account of a necessary relativity correction in cases involving high speeds. This equation does not, however, purport to resolve the serious difficulty with which they and we are yet confronted, that of substituting new concepts of the nature of space, time, and matter.

If, however, we once again remind ourselves that the impressions that come to us directly through our senses can at best be a seriously incomplete counterpart of a vast universe of reality, that many of the concepts that have been handed down to us have originated in a process of thinking that has involved mathematical symbols and operations, that all of our physical laws are dependent in some way or other on a process of inductive reasoning that is inconclusive, and that there is no justification for concluding that the world of reality is the world of perception, however much it may have been and may continue to be modified by scientific instruments, by mathematics, or by other logical processes, we may be able to reconcile ourselves to a new view of the physical world about us.

The dancing, vanishing, fuzzy pygmies are indeed fantastic people, but the dancing, vanishing, wavy, evasive electrons, positrons, neutrons, and photons, may prove to be quite the ordinary fundamental entities.

The sun continues to rise and set and the macroscopic world of perception in which dwelled the men of antiquity, the Egyptians, the Babylonians, the Arabians, the Greeks, continues to be the world in which we, the men and women of 1942, try as best we can to live, sometimes at peace and sometimes at war. As a physical world it is relentless and without emotion. It is but a part of a vast universe that transcends it. Inherent in these fundamental entities, fundamental laws, and fundamental concepts, there is nothing that even suggests the power to reflect, to wonder, and to investigate, but, as a physical world of great complexity it is at least intriguing to the intelligence that transcends it.

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